

CLAIMS:

1. In an extrusion apparatus having an extrusion head including a liquifier which receives a solid element of a modeling material, heats the modeling material, and outputs a flow of the modeling material at an output flow rate while the extrusion head moves along a predetermined tool path at an extrusion head velocity, the apparatus using a material advance mechanism to supply the solid element of modeling material to the liquifier at an input rate which controls the output flow rate, a method for controlling the output flow rate comprising:
  - determining an extrusion head velocity profile based on the tool path; and
  - controlling the input rate of modeling material to the liquifier to produce an output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile.
2. The method of claim 1, wherein determining the extrusion head velocity profile comprises:
  - determining maximum extrusion head velocities for portions of the tool path based on shapes of the portions of the tool path; and
  - determining extrusion head accelerations and decelerations that are continuous.
3. The method of claim 2, wherein the extrusion head accelerations and decelerations have constant finite jerk terms.

4. The method of claim 2, wherein the extrusion head accelerations and decelerations have jerk terms with an absolute value below a predetermined threshold based on a capacitance of the liquifier.
5. The method of claim 1, wherein the extrusion head velocity profile is an S-profile.
6. In an extrusion apparatus having an extrusion head including a liquifier which receives a solid element of a modeling material, heats the modeling material, and outputs a flow of the modeling material at an output flow rate while the extrusion head moves along a predetermined tool path at an extrusion head velocity, the apparatus using a material advance mechanism to supply the solid element of modeling material to the liquifier at an input rate which controls the output flow rate, a method of controlling the output flow rate comprising:
  - determining an extrusion head velocity profile and an extrusion head acceleration profile based on the tool path;
  - calculating the input rate of modeling material to the liquifier required to achieve an output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile, the input rate being calculated based on the extrusion head velocity profile, the extrusion head acceleration profile and a time constant; and
  - controlling the input rate of modeling material to equal the calculated input rate.

7. The method of claim 6, wherein calculating the input rate of modeling material to the liquifier comprises solving a differential equation that governs the performance of the liquifier.

8. The method of claim 7, wherein the differential equation is:

$$Q_i = A * (V_{xy} + (\tau * A_{xy}))$$

where  $Q_i$  is the input rate,  $A$  is a cross-sectional area of a bead of extruded modeling material,  $V_{xy}$  is the extrusion head velocity,  $\tau$  is the time constant, and  $A_{xy}$  is the extrusion head acceleration.

9. The method of claim 6, wherein determining the extrusion head velocity profile comprises:

determining maximum extrusion head velocities for portions of the tool path based on shapes of the portions of the tool path;  
and

determining extrusion head accelerations and decelerations that are continuous.

10. The method of claim 9, wherein the extrusion head accelerations and decelerations have constant finite jerk terms.

11. The method of claim 9, wherein the extrusion head accelerations and decelerations have jerk terms with an absolute value below a predetermined threshold based on a capacitance of the liquifier.

12. The method of claim 6, wherein the extrusion head velocity profile is an S-profile.

13. An extrusion apparatus comprising:
  - an extrusion head movable along a predetermined tool path at an extrusion head velocity;
  - a liquifier carried by the extrusion head which receives a solid element of a modeling material, heats the modeling material, and outputs a flow of the modeling material at an output flow rate;
  - a material advance mechanism which supplies the solid element of modeling material to the liquifier at an input rate that controls the output flow rate;
  - a modeling system for determining an extrusion head velocity profile based on the tool path; and
  - a control system for providing control signals to the material advance mechanism, the control signals commanding operation of the material advance mechanism to have an input rate of modeling material to the liquifier that produces an output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile.
14. The apparatus of claim 13, wherein the modeling system is operable to determine maximum extrusion head velocities for portions of the tool path based on shapes of the portions of the tool path, and to determine extrusion head accelerations and decelerations that are continuous.
15. The apparatus of claim 14, wherein the extrusion head accelerations and decelerations have constant finite jerk terms.

16. The apparatus of claim 14, wherein the extrusion head accelerations and decelerations have jerk terms with an absolute value below a predetermined threshold based on a capacitance of the liquifier.

17. The apparatus of claim 13, wherein the modeling system is operable to determine an S-profile for the extrusion head velocity profile.

18. The apparatus of claim 13, wherein the control system is operable to calculate the input rate of modeling material to the liquifier required to achieve the output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile based on the current extrusion head velocity, a current extrusion head acceleration and a time constant.

19. The apparatus of claim 18, wherein the input rate of modeling material to the liquifier is calculated by the control system by solving a differential equation that governs the performance of the liquifier.

20. The apparatus of claim 19, wherein the differential equation is:

$$Q_i = A * (V_{xy} + (\tau * A_{xy}))$$

where  $Q_i$  is the input rate,  $A$  is a cross-sectional area of a bead of extruded modeling material,  $V_{xy}$  is the current extrusion head velocity,  $\tau$  is the time constant, and  $A_{xy}$  is the current extrusion head acceleration.

21. In an extrusion apparatus having an extrusion head including a liquifier which receives a solid element of a modeling material, heats the modeling material, and outputs a flow of the modeling material at an output flow rate while the extrusion head moves along a predetermined tool path at an extrusion head

velocity, the apparatus using a material advance mechanism to supply the solid element of modeling material to the liquifier at an input rate which controls the output flow rate, a method for controlling the output flow rate comprising:

receiving a predetermined extrusion head velocity profile based on the tool path; and

controlling the input rate of modeling material to the liquifier to produce an output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile.

22. The method of claim 21, wherein the extrusion head velocity profile has accelerations and decelerations that are continuous.

23. The method of claim 22, wherein the extrusion head velocity profile is an S-profile.

24. An extrusion apparatus comprising:  
 an extrusion head movable along a predetermined tool path at an extrusion head velocity;  
 a liquifier carried by the extrusion head which receives a solid element of a modeling material, heats the modeling material, and outputs a flow of the modeling material at an output flow rate;  
 a material advance mechanism which supplies the solid element of modeling material to the liquifier at an input rate that controls the output flow rate; and

a control system for providing control signals to the material advance mechanism, the control signals commanding operation of the material advance mechanism to have an input rate of modeling material to the liquifier that produces an output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to an extrusion head velocity profile based on the tool path.

25. The apparatus of claim 24, wherein the extrusion head velocity profile has accelerations and decelerations that are continuous.

26. The apparatus of claim 25, wherein the extrusion head velocity profile is an S-profile.

27. The apparatus of claim 24, wherein the control system is operable to calculate the input rate of modeling material to the liquifier required to achieve the output flow rate of modeling material from the liquifier that is proportional to a current extrusion head velocity corresponding to the extrusion head velocity profile based on the current extrusion head velocity, a current extrusion head acceleration and a time constant.

28. The apparatus of claim 27, wherein the input rate of modeling material to the liquifier is calculated by the control system by solving a differential equation that governs the performance of the liquifier.

29. The apparatus of claim 28, wherein the differential equation is:

$$Q_i = A * (V_{xy} + (\tau * A_{xy}))$$

where  $Q_i$  is the input rate,  $A$  is a cross-sectional area of a bead of extruded modeling material,  $V_{xy}$  is the current extrusion head velocity,  $\tau$  is the time constant, and  $A_{xy}$  is the current extrusion head acceleration.